

# MODELLING AND STRATEGIES FOR IMPROVED URBAN CLIMATES

Invited paper

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## ABSTRACT

The interactions between different natural and artificial elements in the lower urban boundary layer produce patterns of varying local climate conditions very sensitive to structural changes. An intelligent planning of the urban environment leading to an improved local climate can have lots of benefits such as energy saving effects or the reduction of health risks which finally leads to an improved life quality. The multitude of different processes makes it impossible to assess the impacts of changes on local climate without the help of numerical models.

Urban structural changes can be divided into two groups: First, large scale changes such as the complete redevelopment of urban areas and secondary, small scale changes within existing structures. In this paper a case study for each case have been analysed using the numerical model ENVI-met [1,2,3]. By the example of thermal comfort it is shown how specialised models can help in assessing the effects of local changes on human comfort inside the structures. The transient 2-node model dPET based on MEMI [4,5] is used to calculate the interactions between the human body and the thermal environment. It is shown that complex biometeorological models can give additional information about the effects of urban changes on human thermal conditions not obtainable by other methods.

## INTRODUCTION

Sustainable cities for the next millennium need urban management processes that consider the influence of structural development on local climate. Intelligent strategies for improved urban climates are not just for cosmetic reasons, they have direct effects on different areas of daily social and economic life:

This includes:

- Saving energy by optimized heat distribution, usage of low-energy architecture and natural energy resources
- Reducing health risks by guaranty the cities ventilation and decreasing the near surface pollutant concentrations
- Improving life quality by creating comfortable bioclimate conditions

Microscale numerical models offer the opportunity to feign different planing scenarios in order to optimize planing decisions. Especially in urban climatology, the list of physical processes and the number of non-linear interactions makes it impossible to assess the impacts of changes and modifications without expert systems such as numerical modeling software.

Changes in the urban environment can be divided into two groups: Larger scale changes (*General Structural Changes*), for example redevelopment of complete areas, and into smaller scale changes (*Structural Modifications*) within given structures such as greening of street canyons, roof tops or facades. Both scales include different difficulties and options for planers to optimise local urban climate.

In this paper a short overview is given about the possibilities of using numerical models as tools in urban climatology and city planing. The microscale climate model ENVI-met [1,2,3] was used to simulate a case study of a large scale change as well as a case study of a smaller scale change. ENVI-met is a three-dimensional non-hydrostatic model and able to calculate different processes in, at and between different urban elements with a high resolution and transient over a diurnal cycle. The model itself is not presented here furthermore, for details see paper “*Simulating*

*microscale climate interactions in complex terrain with a high-resolution numerical model (...)*” by the same author or visit the ENVI-met website [3].

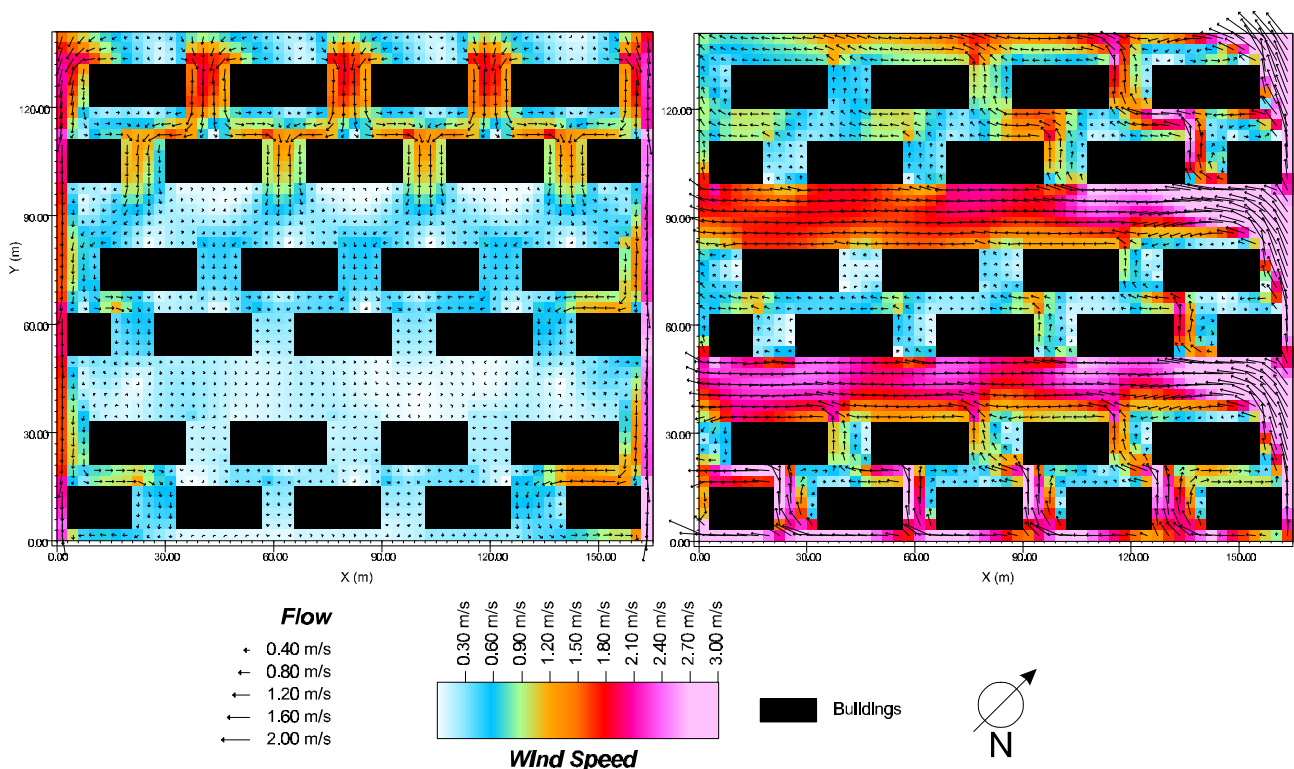
### ANALYSING THE IMPACTS OF GENERAL STRUCTURAL CHANGES ON LOCAL CLIMATE

There is a great variety of reasons for structural changes in the urban environment and their final aims are diverse. It must be admitted, that improving local urban climate is only one objective in planing along with others of similar importance. Nevertheless, although often implied, the consideration of local climate must not necessarily interfere with economic interests: Climate-adapted planing can rather help to reduce cost, for example by saving energy cost for air conditioning.

This can be show with a simple example: A common urban climate problem in cities of South Australia or other places on the world with temperate climate are the different types of winds and breezes passing the cities. In wintertime, it is desirable to keep the cold inland winds away from the houses, but during the warmer seasons it is important to ensure a ventilation by summer breezes (see [6]).

If it were possible to assemble the buildings so that they form a kind of selective filter for different types of wind, it could save a lot of energy in summer as well as in winter. It is a typical task for numerical models to look for the most effective building constellation.

Figure 1 shows the interactions between street layout and air flow for a typical SW Australian city calculated with ENVI-met. It is assumed that the street orientation follows approximately the coastline with cold winter winds coming from inland (NW, 0° in the model due to rotation) and summer breezes coming from the ocean (E, 135° in the model). For a better comparison, in both cases the wind speed is set to 3 ms<sup>-1</sup> in 10 m above ground over flat terrain. Figure 1 shows the horizontal flow field in 2.4 m above ground (z=4 model level) as vector plot as well as the wind speed distribution for the winter situation on the left and for the summer on the right. No thermal effects were considered in this simulation.



**Figure 1: Flow field and wind speed in 2.4 m height for a typical winter (left) and summer situation (right) for a SW Australian city**

It can be seen, that in winter the building layout blocks the cold inland winds from passing through the structure. In summer, the breezes can blow through and ventilate the streets and the buildings.

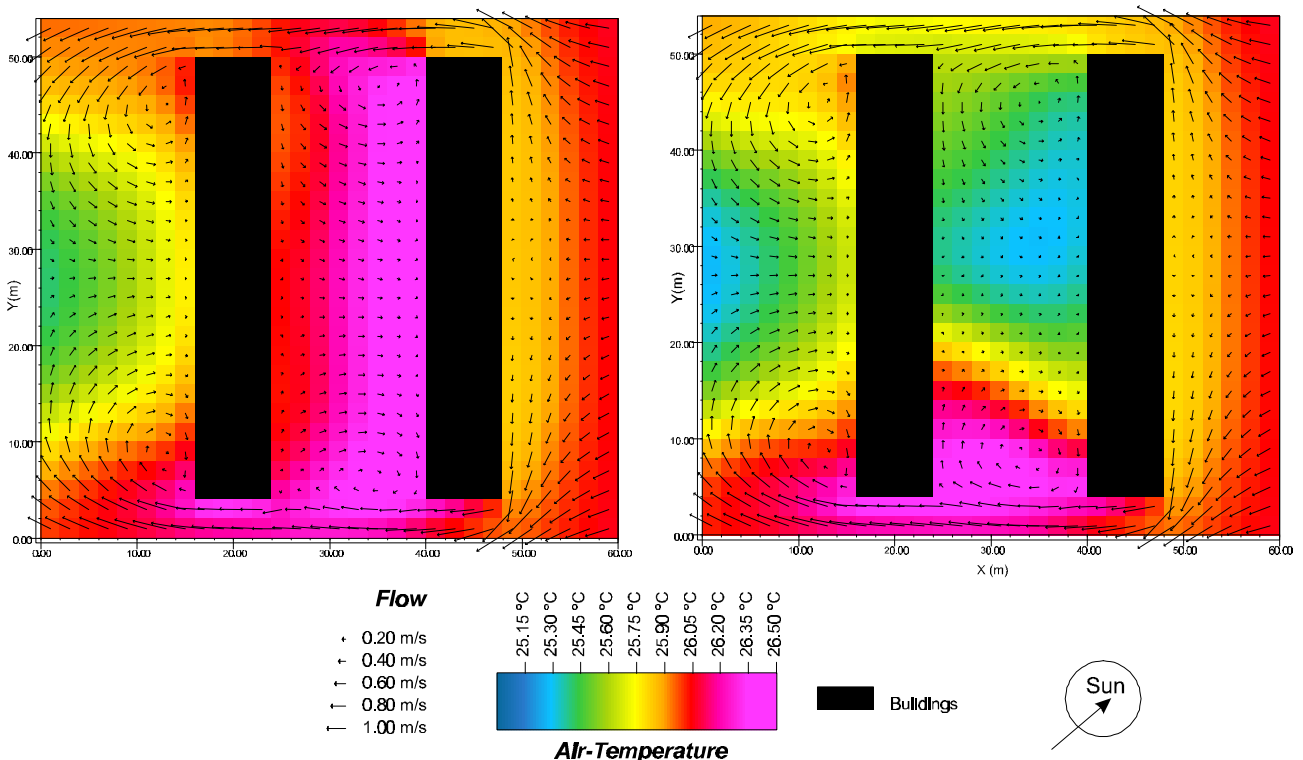
Although it is not recommendable to reduce wind speed near to zero because a minimal ventilation must be insured to blow away pollutants, this example shows, how numerical simulations of building structures can help in optimising climate conditions.

### ANALYSING THE IMPACTS OF STRUCTURAL MODIFICATION ON LOCAL CLIMATE

In most cases the options for optimising the urban environment with respect to local climate are limited because the general city structures cannot be changed. What remains as an option for improvement are small changes within the given structures. To simulate the effects of these small scale changes there is a need for high-resolution models which can accurately represent the properties and the interactions between different urban elements such as building walls and roofs, paved surfaces, natural soils or vegetation in different sizes and types. This is only insured, if the model calculates transient over a complete diurnal cycle using a three-dimensional domain. These computer models require a huge amount of computer power, so it is not surprising that these models began to develop years a few years go.

One possibility for structural modifications which experiences increased consideration in the last years are the benefits of urban vegetation to avoid heat stress. Although the qualitative effects of urban vegetation on the thermal conditions are trivial, there is a lack of quantitative information in order to assess the benefits of greening campaigns.

To study the effects of urban vegetation on local climate a quite simple case study of a North-South orientated street canyon (width 16 m) with homogenous buildings (height 16 m) on both sides is used. The vegetation is represented by 20 m high deciduous trees with a dense crown layer (Leaf Area Density Profile 0.00, 0.00, 0.15, 0.15, 0.65, 2.15 2.18, 2.05 1.72, 0.00  $m^3m^{-2}$  for  $z= 2, 4, 6, \dots 20$  m). The simulation was carried out for Bochum, Germany at  $53^\circ N 7.5^\circ E$ . Figure 2 shows the distribution of wind and temperature in 1.8 m height at 14.00 CET on the 23<sup>rd</sup> of June after 32 hours of simulation time.



**Figure 2: Flow field and air temperature for the canyon without trees (left) and with trees (right) in 1.8 m height at 14:00 CET**

Inside the green canyon, the air temperature is around 1.0 to 1.3 K lower than in the treeless case. Below the trees, wind speed is a little lower and vortex eddies at the end and at the beginning of the canyon can extend a bit further into the street because the overlying vertical vortex eddy between the buildings is suppressed by the tree crow layer.

On the southern end of the street a new hot spot can be observed. Here the trees do not shade the ground surface but reduce wind speed so that air exchange is less effective than in the street without trees.

### **FROM 'FIRST-ORDER' TO 'SECOND-ORDER' RESULTS**

In analogy to turbulence model classification, we may call primary model data like flow, temperature, radiation etc. 'first-order' results. They are based on the dynamics of the environment and obtained by solving the principal physical equations for motion, thermodynamics or similar laws. Unfortunately, these results do not directly provide us with information about the effects of changes on people living in these structures.

Anyone using numerical models in urban planning has the problem to extract and assess these information out of that 'first-order' results which can be hard, especially if a campaign has to be justified from an economic point of view. If we look at the changes in air temperature from the example above, we find only small differences between the green street canyon and the case without trees. It is hard to tell, if and how much this improves the thermal sensation of people living in this structure.

From this point of view, it is essential that numerical models do not only provide first-order results but give more information about the consequences of the calculated numbers, which we may call 'second-order' results.

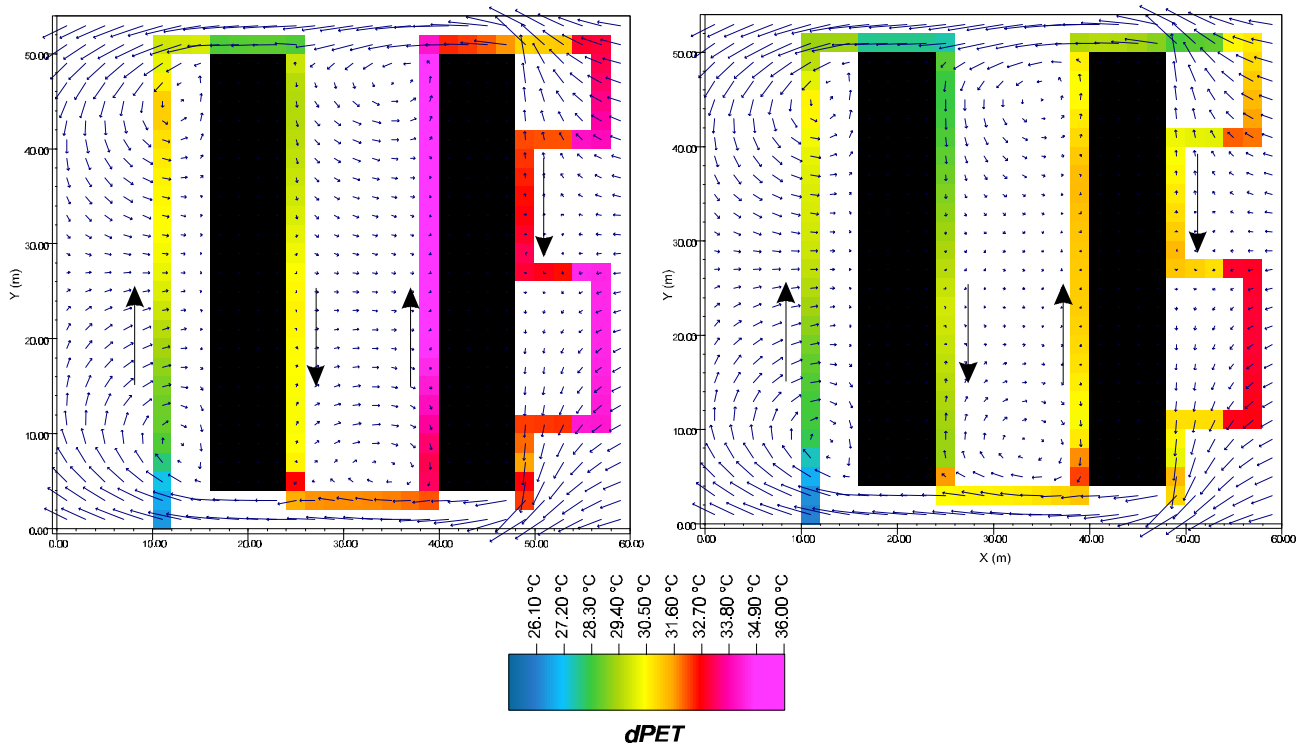
Inside urban structures the human body is exposed to a multitude of influencing factors ranging from a modified radiation budget to pollution by gases, particles or noise.

Even if we restrict ourselves to the thermal complex, there is still a huge number of processes which have to be considered when assessing climate conditions. To get 'second-order' information the model ENVI-met was extended with several biometeorological models which post-process the calculated results. In this paper the most complex model, the 'dPET' model, is presented.

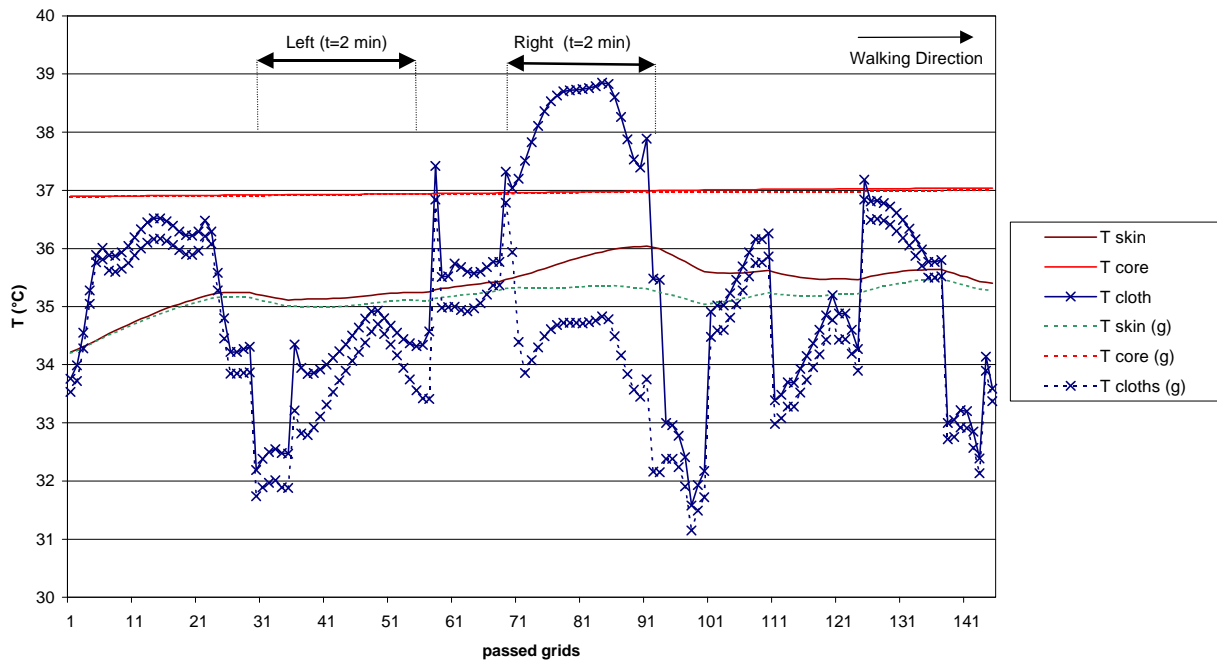
### **THE dPET MODEL IN ENVI-MET**

The (d)PET ([dynamic] Physical Equivalent Temperature) Model is based on the transient version of the *Munich Energy-Balance Model for Individuals* (MEMI) by P. HÖPPE [4,5]. MEMI is a complex 2-node model calculating different body parameters such as skin-, core- and clothing temperature, sweating or energy exchanges at the body surface. The central model variable is the PET value, which is that operative temperature at indoor conditions which would cause the same energy balance of the body as the evaluated outdoor conditions. Based on MEMI, the model was extended to the dPET model in order to allow a direct coupling with the results obtained from ENVI-met. The dPET model allows a "virtual walk" through the model environment on a user defined path. It is nested in the ENVI-met environment and can handle up to 100 different walkers with different walking routes starting their walk at given time intervals. Every second in model time, the dPET model is provided with new information from the main model with respect to the present position of the walker inside the model domain.

For this case study one walker is defined, starting the walk at 14:00 CET. The layout of the selected route can be seen in Figure 3. The left side of the street is shaded by the buildings, whereas the right pavement is only shaded in case of the green street canyon. After leaving the canyon, the walker changes between the shaded and the sunlit areas behind the right building to show the effects of additional shortwave radiation after passing the street canyon. The length of the street canyon is 46 m and it takes the walker (male, 35 years old, clothing insulation 0.5 clo) approximately 2 min to pass one side. Figure 3 shows the calculated dPET temperature for the grid points along the way.



**Figure 3: dPET experienced by the virtual walker while walking through the model environment at 14:00 CET (left: without trees, right: with tree cover)**



**Figure 4: Temperatures of the human thermal complex while walking through the structure. Dotted lines (g) indicate the temperatures calculated for the green street canyon**

Neglecting the first meters of the walk, the dPET temperature has a local minimum when reaching the northern end of the street due to high wind speed and missing shortwave radiation. Walking along the shaded left side, the dPET value is nearly constant with small variation as wind speed varies a little. As an effect of decreased air temperature the values

are around 1 K lower for the green case. Walking on the other side of the street, the exposure to the sun combined with relative low winds cause an increase of dPET up to 36 °C whereas in the street canyon with tree cover the dPET value is around 31 °C at the end of the street. Looking at the situation behind the right building the big advantage of transient models turn out: although the meteorological situation upstream of the street is fairly the same for both scenarios, the dPET values differ. This is because the model takes in account the heating of the body experienced in the unshaded street. The additional input of sun radiation leads to a different thermal sensation for a person who have walked through a shaded street before than for a person who walked the unshaded passage. This seems to be trivial because it corresponds to our personal experiences, but is far away from being trivial to be considered in a numerical model. Figure 4 shows different temperatures of the human thermal complex while walking through the environment. 'Left' and 'Right' indicate the sections when walking on the left and right sidewalk. It can be seen that the skin temperature in the treeless case remains higher even at the end of the walk. Steady-state models, for example the PMV-Model [7,8] would have calculated the same thermal comfort for the areas upstream of the street canyon regardless to the situation inside the street.

Using transient models like dPET could also lead to a different interpretation of the results: The effects of greening a street canyon are not necessarily restricted to the street canyon itself although meteorological data might suggest that. Taking in account that people move through urban structures, occasional street with tree cover could keep the energy stored inside the body below a critical mark, so that the complete urban structure could benefit from the change.

## CONCLUSIONS

Two case studies have been presented in order to show how numerical models can help to analyse the interactions between urban structures and local climate. With high-resolution models such as ENVI-met it is not only possible to analyse the effects of general structural changes such as different building constellations, but also to predict the interactions between small structural changes and local climate.

It is often difficult to draw conclusions from the physical based model results to the effects on human comfort inside the urban structures. Calculated model results must be coupled with additional models, for example from biometeorology, to get 'second-order' information about consequences of the calculated results on urban life. By the example of human thermal comfort it was shown, that complex biometeorological models such as dPET or MEMI allow a very detailed simulation of the interactions between the human body and the environment. They do not only provide the user with summarised information about thermal conditions, they are also able to obtain new information which could lead to a different assessment of calculated results.

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